REMARKS/ARGUMENTS

These Remarks are responsive to the Office Action mailed April 5, 2004 ("Office Action"). Claims 1-29 are all the claims pending in the present application. Applicants respectfully request reconsideration of the rejections of claims 1, 2, 5, 12, 15-19, 21, 23 and 26-29 for at least the following reasons.

Allowable Subject Matter

Applicants thank Examiner Chang for his indication that claims 3-4, 6-11, 13-14, 19, 20, 22 and 24-25 contain allowable subject matter.

Summary of Image Recognition Theory

Applicants have provided the following summary of some of the theoretical underpinnings involved in the present disclosure. It is Applicants' intent to describe how the current claims differ from the cited prior art, provide additional understanding of the claimed invention and highlight some of the features of the claimed invention.

The Generalized Hough Transform

The Hough transform, as generalized by Ballard, starts by choosing a reference point for the object's outline curve. For each point on the outline curve a vector, r, to the reference point is computed and the local tangent to the curve is computed. A key point for Ballard, is the use of an "edge operator" to compute the tangent at each edge point. The angle, ϕ, between the curve tangent and the vector r, is used as an index to store r into an "R-table." Because ϕ is a difference of angles, it is independent of rotation and translation.

To find an object's outline curve in an image, Ballard measures the tangent at each candidate edge point, x. Using this tangent as a "baseline" Ballard looks at each index angle, ϕ, of the R-table and where there is a value r, an accumulator is incremented with the $x+r$. Peaks in this accumulator indicate the location of the object

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specified by the R-table. This method is not rotationally invariant, as the tangent at **x** varies with rotation. Ballard adds additional parameters for scale and rotation, giving a 4-dimensional accumulator space. Ballard suggests using pairs of edge points to reduce the accumulator space dimensionality, but Applicants respectfully submit that this is not equivalent to a curvature measure.

The claimed method uses a novel estimate of curvature, the 'h' parameter, as the index into the R-table. In contrast to the cited art, the claimed method does not rely on "edge operators" to compute this index. Rather, the claimed invention records a kind of radial vector (but not in the manner disclosed by McDonald and Terzain) and an angle that is rotation and translation invariant.

Because h, Applicants' index ("key") into the R-table is rotationally invariant and Applicants' method does not consider scale, Applicants only need a two dimensional accumulator. This means that accumulation and search are very fast, while still maintaining pattern translation and rotation invariance. Each entry in Applicant's R-table contains a vector and the translation and rotationally invariant angle. The vector is used to address the X,Y accumulator table and the angle is used later to estimate the found object contour's angle. Applicants call this method the "Curvature Hough Transform to distinguish it from "Ballard's Generalized Hough Transform."

Curvature, κ, is the derivative (rate of change) of the tangent angle, φ, along a curve. On an analytic curve given in parametric form, $x = f_x(t)$, $y = f_y(t)$ one has:

$$\kappa = \frac{d\phi}{ds} = \frac{\dfrac{d\phi}{dt}}{\sqrt{\left(\dfrac{dx}{dt}\right)^2 + \left(\dfrac{dy}{dy}\right)^2}}$$

where s is the arc length (Euclidian distance). Unfortunately, digital images are "blocky" and not analytic. In a digital image, one might first estimate local tangent angle, φ, from an oriented edge finder (e.g., a Sobel operator can be modified to output angle as well as edge strength) or by the angle between two successive points on an outline curve.

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Curvature might then be approximate as the finite difference of two successive, local edge orientations (ϕ) on the curve points. This method does not work well in practice, because it is difficult to reliably estimate the local tangent angle and because both differential operations amplify noise – both image and sampling noise.

Previous work has shown that representing object outlines by an ordered set of curvature values gives a model that disregards (is "invariant to") rotation and translation. Curvature is a second derivative operation where the first derivative takes out position to give edge orientation and the second derivative takes out orientation to give curvature. A model encoding object outline curvature can then be used to find and identify objects in an image regardless of their position and orientation (but not size).

Applicants have developed such a method for encoding and matching objects based on their contour curvature and their claimed "Curvature Hough transform."

Distinctions Over The Art of Record

The following paragraphs provide additional distinctions over the art of record.

Yamada, et. al. (U.S. Patent 5,033,099) creates a model of an object's outline by "selecting evaluation points," storing the local outline direction (outline *angle*, not curvature) at these evaluation points, and "storing shift vectors indicating the direction and distance from one evaluation point to the next...." To find target object outlines in the image, an edge operator generates a "directional plane" for each of 8 possible directions of edges in the image. A "counter plane" (accumulator) is then "shifted with respect to the directional planes along a path specified by the shift vectors of the model and, at each shift, values in the directional plane specified by the model for the relevant evaluation point are added to the counter positions of the counter plane." This can be seen as a form of guided correlation, of models to target objects, similar to a Hough transform. Peaks in the "counter plane" indicate a model match and location. The proposed implementation allows the accumulation to be done in parallel. For example, following the correlation "path" for a model of the letter 'A' will indicate the location of all

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A's in a document. There is no use of curvature (other than to suggest selecting evaluation points where the "curves are mild") and no mention of the Hough transform.

McDonald, et. al. (U.S. Patent 5,600,733) describes an improvement on a "pattern recognition system" used in semiconductor wire and die bonding. The operator selects a "teach window" that encompasses the object to be identified. An "eye point" – a reference point – is established and vectors (direction and length) from this point to the object's edges are recorded as the object model. The object's centroid (the average X and Y position of all outline points) is also recorded. To recognize an object, "candidate eye points" are tested and the one that gives the best match to the vector model is chosen. The centroid location for the outline points chosen by the best eye point is computed and this gives a sub-pixel (fraction of a pixel position) location for the pattern. This method requires that the pattern being matched is already known (e.g., a particular bond pad) and that its approximate position is known. What is of interest is the sub-pixel position computed by the centroid, based on the outline points chosen bythe best "eye point". It has some tolerance for changes in pattern size (scale) and less for rotation. There is no mention or use of curvature or Hough methods.

Michael (U.S. Patent 5,943,411) gives a method for finding edge contours. Michael first estimates an object edge position (in one direction) to a fraction of a pixel (sub-pixel) measure. His preferred embodiment determines the position using a "first difference signal of a gray value signal taken across the edge contour," and interpolating to find the peak rate of change and hence the sub-pixel edge location. Michael then computes a local orientation for each edge and "the direction and position of the current edge contour point are used to determine the next pixel set," that is, the next pixel in the object's outline. There is no use of curvature or Hough matching methods. The method requires a starting or seed point on the contour (object outline).

Terzian (U.S. Patent 4,901,362) classifies objects by matching their silhouettes – what Applicants are calling the object's outline. For objects, such as boats, that are essentially horizontal, Terian constructs a set of vertical vectors between the bottom and top edges of the outline – say between the waterline and the boat's superstructure.

These vectors are normalized and compared with similarly normalized patterns of known objects. A minimum absolute difference (MAD) matching metric is used. For objects that can have variations on top and bottom a radial method is used. The centroid is first computed. Vectors are constructed from the centroid to the outline. This set of vectors is rotated so that the largest vector occupies the first position; the vectors are normalized (as before) and matched to a similarly constructed set of models, again using a MAD metric. To allow for noise, the vectors are also rotated slightly off of the main peak and tested. To allow for multiple "peak radial vectors", matches are done with other large vectors occupying the first position in the model. For aircraft that can have various aspect ratios, multiple models are used.

This method is similar to McDonald, et. al., in that it uses a set of radial vectors that are normalized to accommodate object size (scale) changes. Terzian also uses the centroid, but not the way McDonald, et. al. does. This method does not use curvature or Hough matching. This kind of method experiences the following drawbacks.

First, it uses the centroid as a "reference point" for computing the radial vectors. Noise and missing points in the outline will shift the centroid and will therefore distort the radial vectors and can disrupt the matching. McDonald, et. al.'s patent avoids using the centroid as an "eye point" for generating their radial vectors, using it only for the sub-pixel location. Second, even if a centroid is "close enough", noise and missing points can cause disrupt matching. Finally, the matching effort goes up as the product of the number of peak vectors time the number of models.

Hough's patent (U.S. Patent 3,069,654) In this patent, the disclosed Hough "transform" and generalized Hough transform methods are computationally too expensive to be practical in practice. Applicants show a use of the *curvature* Hough transform that is robust and efficient at pattern matching.

In summary, with regards to the art of record:

Yamada, et. al. does a kind of Hough transform of edge orientations but Applicants' method does not use edge orientations. Applicants' method is unique in implementation, robustness and speed.

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In contrast to Applicants' method, McDonald, et. al, and Terzian use radial vector models that require a reference point. McDonald searches for the best "eye point" but Terzain assumes it to be the centroid, and this can be a problem. Applicants' method does not require specifying a reference point. Applicants' method uses radial vectors but they are not used as matching elements, the way they are in McDonald, et. al. and Terzian.

Both McDonald, et. al and Terzian's radial vector models can be normalized to give some tolerance to changes in target pattern size. Applicants' method does not use radial vectors as matching elements and so cannot be normalized this way.

McDonald, et. al. uses the centroid to determine the object location to a fraction of a pixel. Applicants also use this well-known method, but improve it by only using points that exist and correspond in both model and target. This eliminates the problem of the centroid being incorrectly shifted by missing points.

Applicants use methods described by Michael and well known in the art to generate sub-pixel positions for outline edge points. However Applicants do not compute or use local edge point orientations to estimate the curve outline or the next point in the curve. Furthermore, Applicants extract and match to all significant contours and hence do not need a seed or staring point.

Standard Hough methods (e.g., Ballard) are too complex and slow for practical use. Applicants' method "keys" the Hough transform using a measure of local curvature and this leads to a two-dimensional accumulator space that is fast to compute and search.

For at least the foregoing reasons, Applicants respectfully submit that claims 1-29 are in condition for allowance and respectfully request that the Examiner so indicate in the next communication from the Office.

A check in the amount of $1237.00 is attached to cover the three (3) month extension of time fee for a small entity, the RCE submission fee and (8) excess independent claims. No other fee is believed due at this time. However, in the event any variance exists between the amount enclosed and the Patent Office charges,
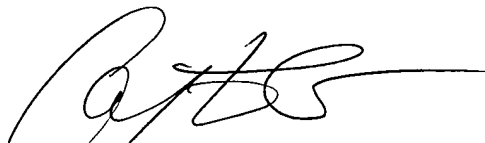
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please charge or credit any difference to the undersigned's Deposit Account No. 50-0206.

Respectfully submitted,

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